II.5 Solid State Energy Conversion Alliance (SECA) Solid Oxide Fuel Cell Program

Objectives

- Develop a fuel-flexible and modular solid oxide fuel cell (SOFC) system (3 to 10 kW) that can serve as the basis for configuring and creating low-cost, highly efficient, and environmentally benign power plants tailored to specific markets.
- Demonstrate a prototype system of the baseline design with desired cost projections and required operating characteristics (Phase I); assemble and test a packaged system for a selected specified application (Phase II); field test a packaged system for extended periods (Phase III).

Approach

Phase I

- Establish a baseline system concept and analyze its performance characteristics.
- Perform a cost study to estimate system costs.
- Develop a robust, reliable high-performance SOFC stack technology amenable to low-cost manufacturing.
- Develop a fuel processor as a pre-reformer for processing a variety of fuels.
- Evaluate system thermal management to establish a suitable recuperation scheme for the system.
- Develop and implement a flexible control structure incorporating required sensors.
- Identify a flexible low-cost power management subsystem.
- Evaluate component integration.
- Design, assemble and test a prototype system to demonstrate performance meeting the program requirements.

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Phase II

- Deliver and test Phase I prototype at NETL.
- Conduct a market study to identify and define a specified application for Phase II.
- Perform system design and analysis to define system configuration and packaging for the selected application.
- Design, manufacture, test, and validate system components and component integration.
- Conduct cost estimate and Design-to-Cost to establish a system cost that meets the Phase II cost goal.
- Assemble and operate a packaged system under required conditions and demonstrate operational characteristics meeting the Phase II requirements.
- Continue technology, engineering, and manufacturing developments for SOFC stacks and balance of plant (BOP) to improve system cost, performance, life, and reliability.

Accomplishments

The major accomplishment is the successful completion of the Phase I prototype testing with the demonstrated performance meeting or exceeding the key Phase I requirements.

- An extensive system build and integration process was conducted to verify/validate/assess the various components and integrated prototype system before the final demonstration testing.
- Demonstration testing was carried out for the prototype. The system demonstrated the performance that met/exceeded the key Phase I minimum requirements. The prototype achieved an efficiency of 41% (vs. 35% requirement) and a degradation rate of 1.8% per 500 hours (vs. <2% per 500 hours requirement). The system operated for 1,720 hours (vs. 1,500 hours requirement) with three thermal cycles (vs. one thermal cycle requirement) and 15 power cycles (vs. nine power cycle requirement). A projected high-volume cost for the system is $724/kW (vs. $800/kW target).
- Phase II of the project has been initiated. Detailed plans and key activities have been developed for Phase II work.

Future Directions

Continue activities defined in the Phase II project plan.

- Deliver a Phase I unit to DOE/NETL.
- Conduct various technology improvement/advancement activities on the SOFC and the BOP to improve system cost, performance, life, and reliability.
- Design, assemble and test a packaged system under required conditions and demonstrate performance meeting the Phase II requirements.

Introduction

This project focuses on developing a low-cost, high-performance solid oxide fuel cell (SOFC) system suitable for a broad spectrum of power generation applications. The overall objective of the project is to demonstrate a fuel-flexible, modular 3-10 kW system that can be configured to create highly efficient, cost-competitive, and reliable power plants tailored to specific markets. The key features of the SOFC system include a fuel-flexible pre-reformer, a low-cost, high-power-density SOFC stack, integrated thermal management, and suitable control and power management subsystems. When fully developed, the system is expected to meet the projected cost of $400/kW.

Approach

The SOFC system is a stationary power module (3-10 kW) capable of operating on different fuels. The system consists of all the required components for a self-contained unit, including fuel cell stack, fuel processing subsystem, fuel and oxidant delivery subsystem, thermal management subsystem, and various control and regulating devices.

- The SOFC is a compact of anode-supported cells (fabricated by the GE HPGS tape-calendering process) and metallic interconnects. The stack design is based on an advanced concept that maximizes cell active area and minimizes sealing. The fuel cell can operate directly on light hydrocarbon fuels and incorporates materials for high performance at reduced temperatures (<800°C). These characteristics provide a low-cost, fuel-flexible fuel cell suitable for operating under various conditions. The tape calendering process for manufacturing thin-electrolyte, anode-supported cells is a potentially low-cost, mass-customization technique suitable for high-volume production and automation using available commercial equipment.
- The fuel processor is a catalytic reactor that functions as a pre-reformer. The system employs an integrated thermal management approach to utilize byproduct heat and reduce heat losses, and, consequently, increase the overall system efficiency. The system also has a flexible control structure that can be modified or optimized for different applications.

The project consists of three phases. Phase I of the project focuses on developing system components having the required operating characteristics, resolving critical technological issues, and demonstrating a prototype system. The Phase I work concentrates on system design and analysis, cost study, stack technology development, fuel processing development, controls and sensors, power electronics, and system prototype assembly and testing. Phase II will demonstrate a packaged system selected for a specified application and further improve technology and assess system cost. Phase III will extend the Phase II effort to field test a packaged system for extended periods to verify all the required performance, cost, reliability, and lifetime for commercial uses.

Results

A prototype system was constructed to demonstrate system performance as required in the Phase I project objectives. This prototype system intended to be flexible and robust to accommodate design changes throughout the entire system integration process. The assembly process began with specifications for various components flowing down from the systems and controls designs via scorecards so that components could be sourced. A computer model and drawing package of the system geometry was also used to guide construction. Although many items were standard components, a number were developed, modified or designed specifically for the program.

The prototype system that was tested can be seen Figure 1. There was an extensive system build and integration process leading to the final testing of the unit which was comprised of the following major steps:

- Component tests to verify basic operation of components in stand-alone testing, develop component performance maps, and support component selection process.
- Cold tests (operation of system with only nitrogen/air and without fuel cell stacks) to validate basic operation of components integrated in system and verify plumbing and electrical wiring.
- Hot tests (operation of system on methane without fuel cell stacks) to verify and tune control system hardware and software, combustor operation and temperature controls, integrated operation of fuel

FIGURE 1. SECA Phase I Prototype System

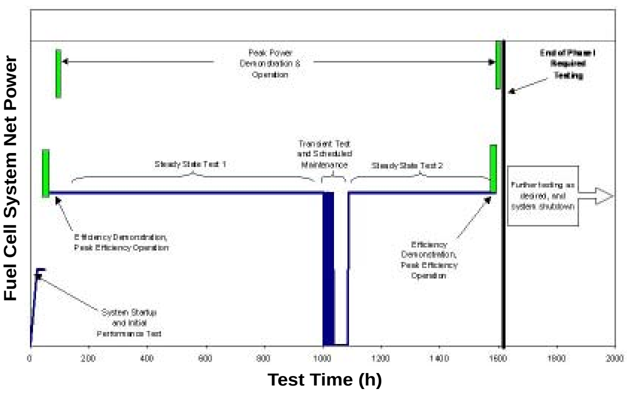

FIGURE 2. Prototype System Test Sequence

processor, and thermal mapping of system and improved insulation.

- Gen 1 System Test (operation of integrated system without power electronics due to half-sized stacks) to verify system operation including stack operation, integrated operation of stacks with fuel processor, thermal self sustaining operation and thermal management, and startup and shutdown strategies.
- Gen 2 System Test (operation of integrated system with power electronics) to demonstrate system operation with performance meeting the Phase I requirements.

The Gen 2 System Test is the final prototype system demonstration test for Phase I. The timeline test sequence for this test is shown graphically in Figure 2. Figure 3 shows the average cell voltage, gross DC

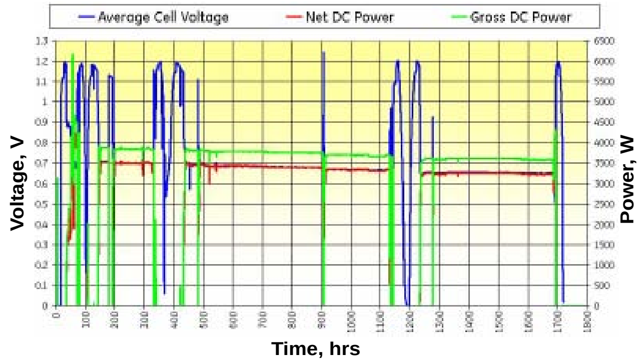

FIGURE 3. Average Cell Voltage, Gross DC Power, and Net DC Power of Prototype System (Average Operating Temperature 800°C)

power, and net DC power of the prototype system over the entire test period (note that the peaks in the figure are those relating to various transient events during the test). The prototype system achieved a peak efficiency of 41%, a peak power of 5.4 kW, and a degradation rate of 1.8% per 500 hours. The system met/exceeded all of the key Phase I minimum. A summary of the Phase I results versus the requirements are given in Table 1.

TABLE 1. Summary of Prototype System Demonstration Test Results

Performance Parameter	Requirements	Results
DC Efficiency	35%	41%
Estimated Cost	<$800/kW	$724/kW
DC Peak Power	3-10 kW	5.4 kW
Steady State Degradation	<2% per 500 hrs	1.8% per 500 hrs
Thermal Cycle	1	3
Power Cycle	9	15
Cycle Degradation	<1%	1.8%
Availability	80%	90%
Test Time	1,500 hrs	1,720 hrs

Conclusions and Future Directions

SECA Phase I was successfully completed. During Phase I, major advances in SOFC technology were made in the areas of performance, degradation/life, stack design, manufacturing, and scaleup. Supporting technology such as fuel processing, controls, power electronics, and thermal management were also developed/matured for integration in an SOFC power system. Phase I culminated in the system test that tied all of these advances in technology together in a prototype system that was able to meet or exceed the key SECA minimum requirements. The system achieved a peak efficiency of 41% (vs. 35% requirement) and a degradation rate of 1.8% per 500 hours (vs. <2% per

500 hours requirement). The system operated for 1,720 hours (vs. 1,500 hours requirement) with three thermal cycles (vs. one thermal cycle requirement) and 15 power cycles (vs. nine power cycle requirement). A projected high-volume cost for the system is $724/kW (vs. $800/kW target).

Phase II of the project has been initiated. Phase II focuses on delivering a Phase I prototype to DOE/NETL, advancing SOFC and BOP technologies to improve system cost, performance, life, and reliability, and demonstrating a packaged system for a selected application.

FY 2006 Publications/Presentations

1. N. Q. Minh, "Solid Oxide Fuel Cell Based Power System Development" 2005 Fuel Cell Seminar Extended Abstracts, Courtesy Associates, Washington, DC, 2005.

2. N. Q. Minh, "Solid Oxide Fuel Cell Technology: Status and Future Direction" Plenary Presentation at the Third International Symposium on Solid Oxide Fuel Cells Materials and Technology" Cocoa Beach, FL, January 20-26, 2006.